10.2 Thermal-Structural Testing

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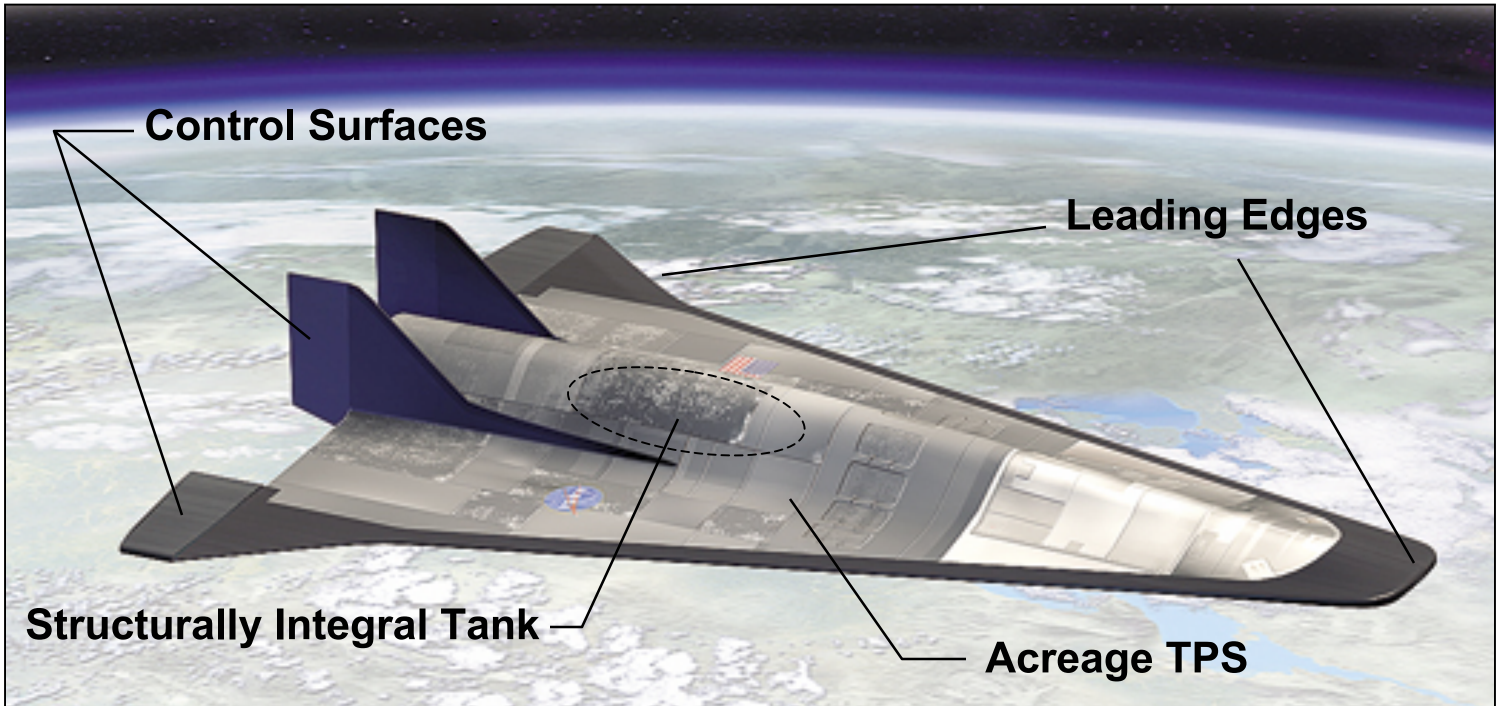
Outline

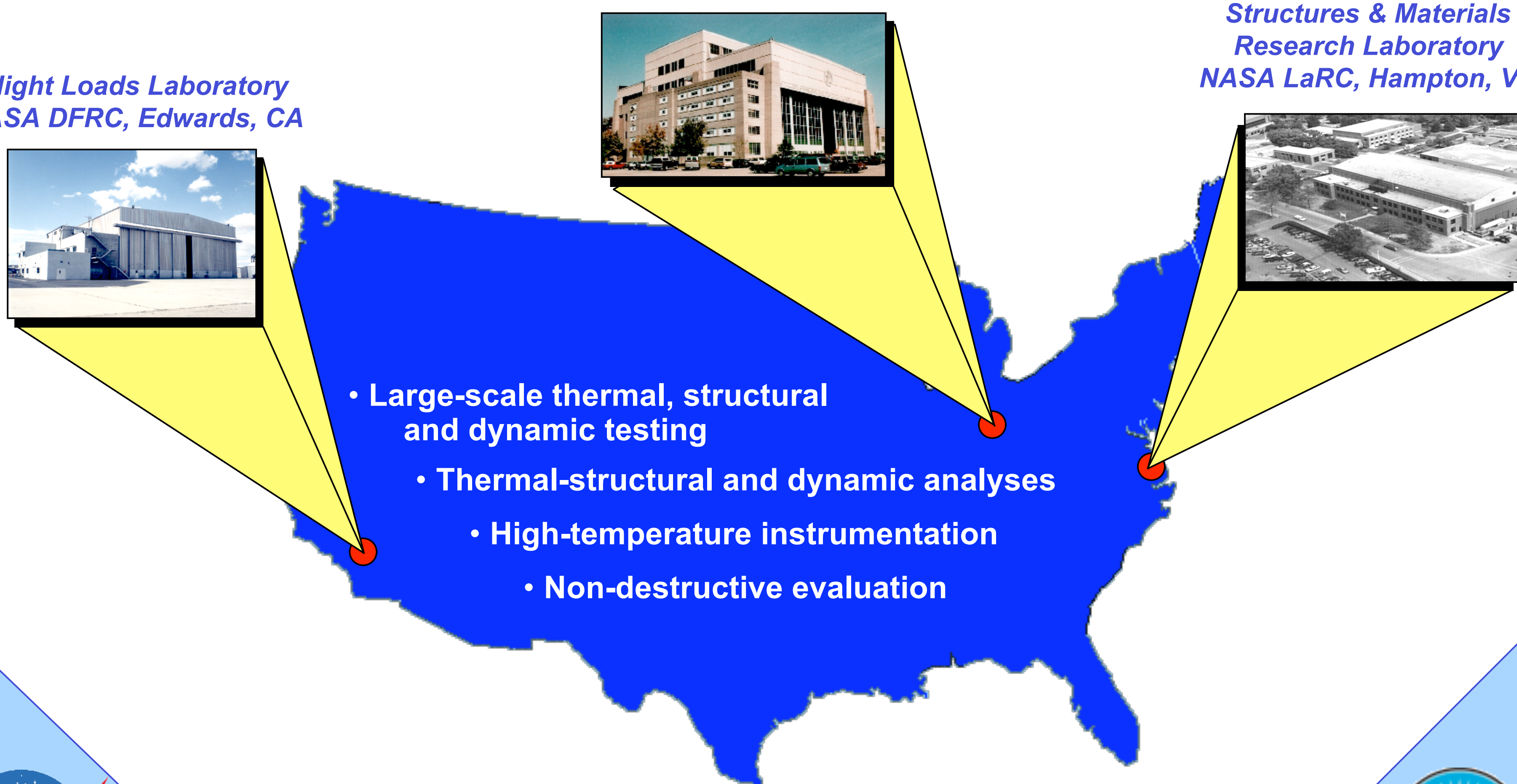
- Thermal-Structural Testing of Hypersonic Vehicles
- Laboratories for Thermal-Structural Testing
- Overview of Past Test Programs
- Test Flow Diagram
- Test Development
- High-Temperature Instrumentation
- Thermal-Structural Testing Challenges
- Current Test Activity

Thermal-Structural Testing of Hypersonic Vehicles



- Leading edges – Arc Jet Test Facilities
- Acreage TPS – Arc Jet / Thermal-Structural Test Facilities
- Control Surfaces – Thermal-Structural Test Facilities
- Structurally Integral Tank – Dedicated facility not in existence

Thermal-Structural Testing Laboratories



- Large-scale thermal, structural and dynamic testing
- Thermal-structural and dynamic analyses
- High-temperature instrumentation
- Non-destructive evaluation

Aircraft Subjected to Heating Tests

- Main landing gear assy
- Nose landing gear
- Ball nose
- Wing
- Horizontal tail

- Entire aircraft

- Horizontal tail

- Entire aircraft

- Entire aircraft

- Canard

- Entire aircraft

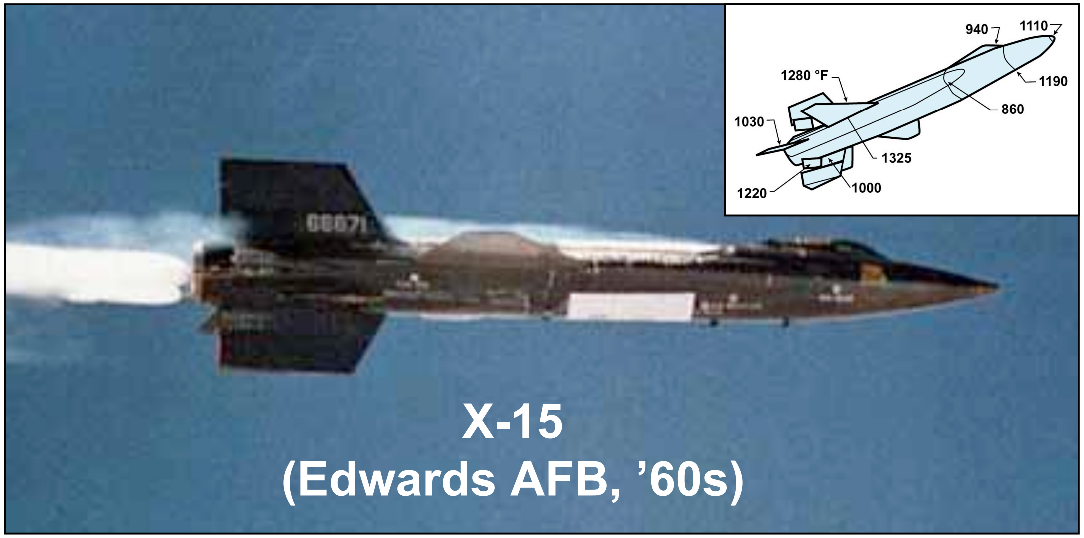
- Entire aircraft

- Elevons
- Wing boxes
- Leading edges
- Forward fuselage

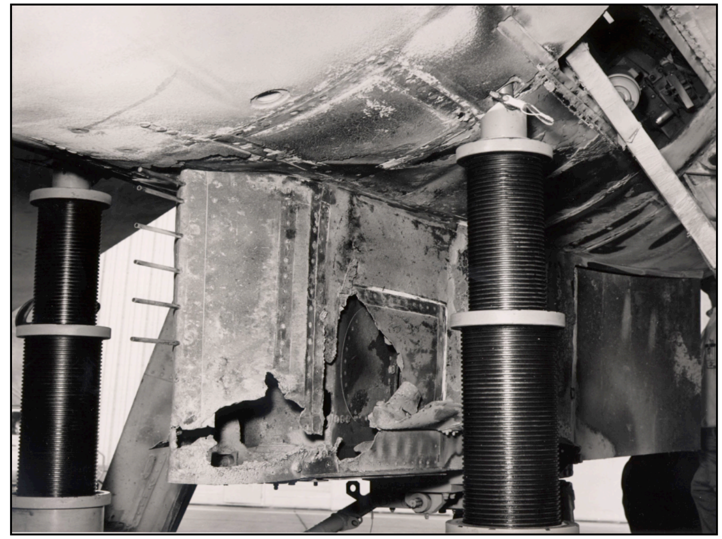
- Bodyflaps

- Ruddervators
- Flaperons

Aircraft Subjected to Heating Tests



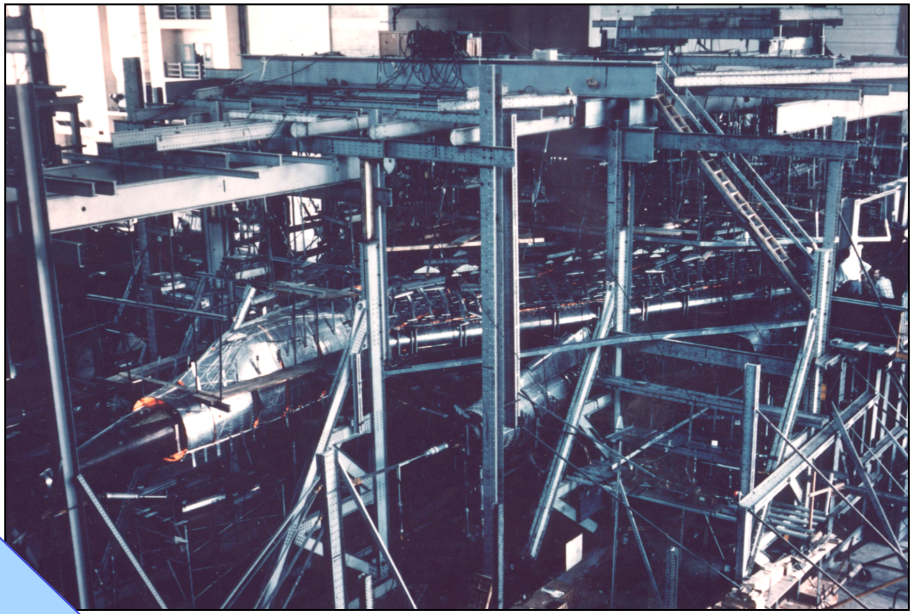
X-15
(Edwards AFB, ’60s)



- **First reusable superalloy (Inconel X) structure designed to withstand the thermal environment of hypersonic reentry**
- **“Heat sink” aircraft**

Aircraft Subjected to Heating Tests

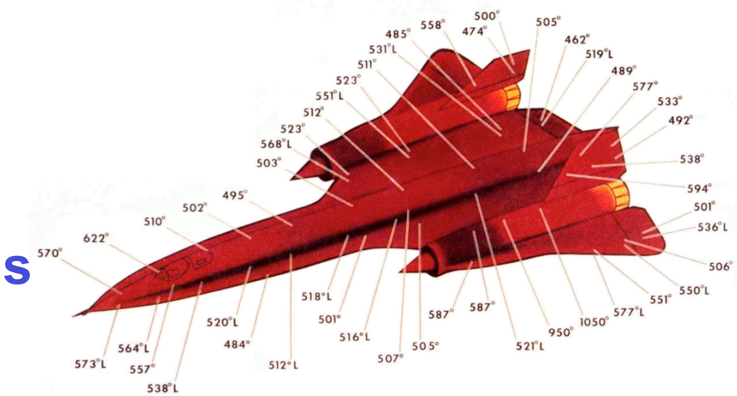
- Static loading at 260°F (Mach 2, 36k ft)
- Simulated fueled and unfueled conditions
- Report No. ASD-TRD-62-595 (AFRL-WP)



B-58 Heating & Loading Test
(AFRL-WP, Bldg 65, ’60s)

Aircraft Subjected to Heating Tests

- Simulated Mach 3 cruise condition
- Tested the effect of elevated structural temperatures on measurements air loads
- Declassified report: NASA TM X-3061

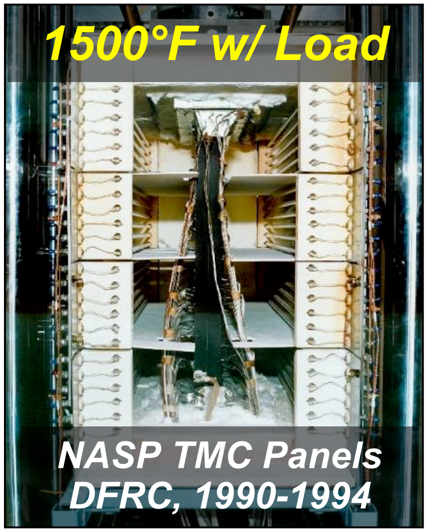


YF-12 Hot Loads Calibration Test
(NASA Dryden, Flight Loads Lab, ’70s)

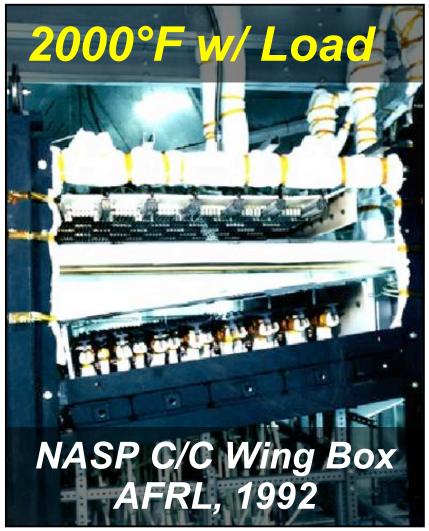
Aircraft Subjected to Heating Tests

- TPS and hot structures
- C/C hot structure control surfaces
- Control surface temperatures in excess of 2500°F

Thermal-Structural Test Programs

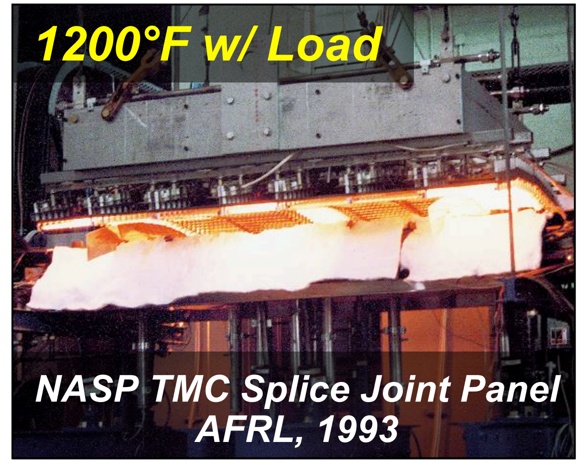


NASP TMC Panels
DFRC, 1990-1994



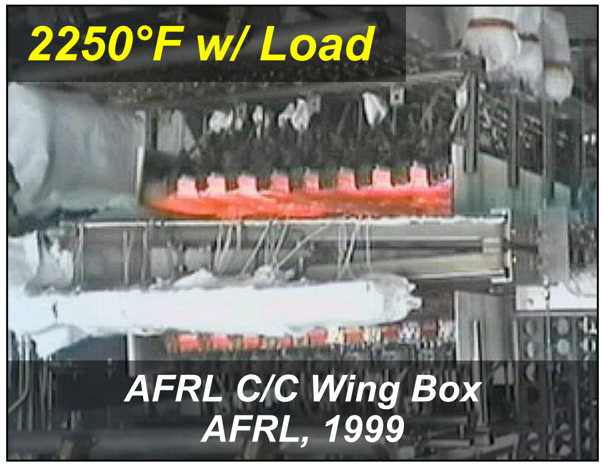
NASP C/C Wing Box
AFRL, 1992

NASP TMC Panel
Joint Test
LaRC, 1993

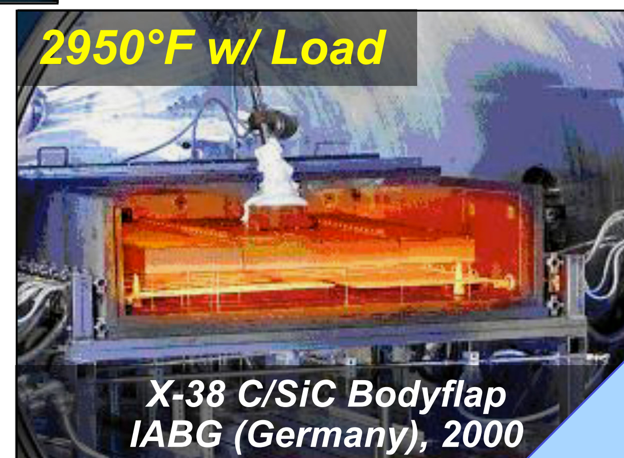


NASP TMC Splice Joint Panel
AFRL, 1993

NASP TMC Side Shear Panel
DFRC, 1995

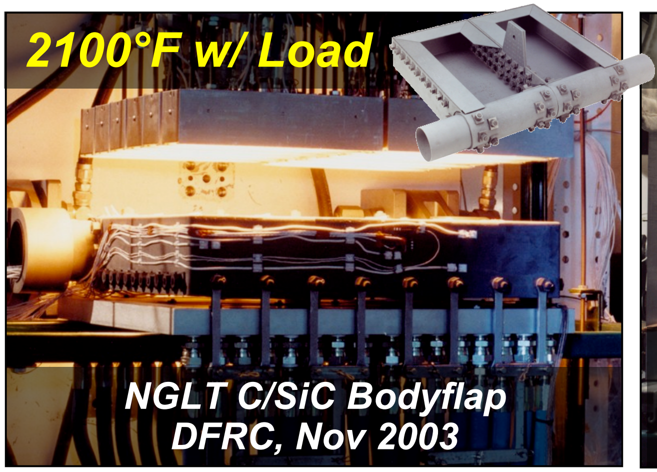


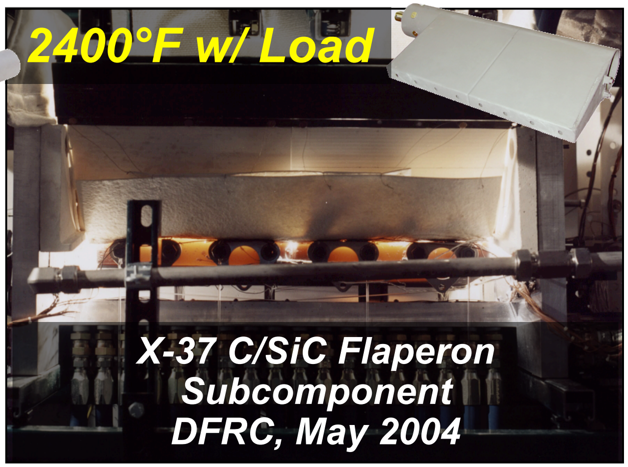
AFRL C/C Wing Box
AFRL, 1999

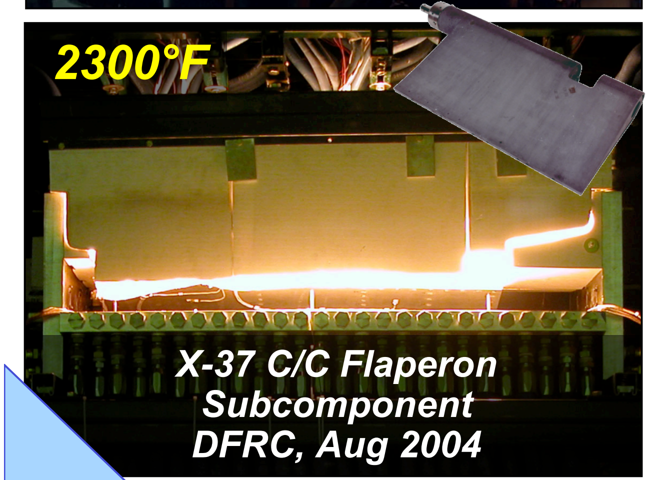


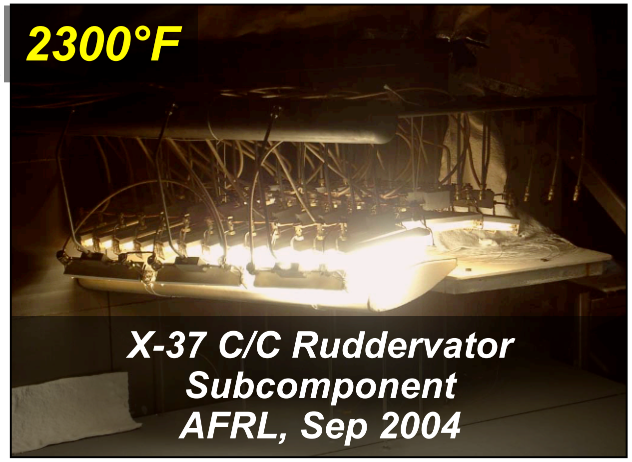
X-38 C/SiC Bodyflap
IABG (Germany), 2000

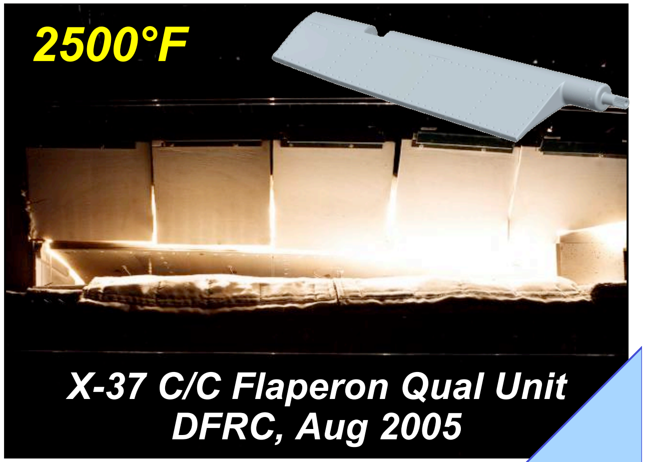
Thermal-Structural Test Programs





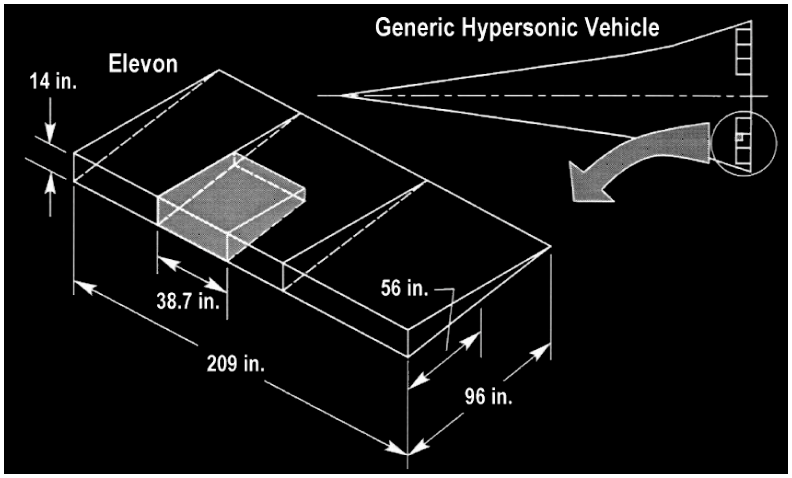


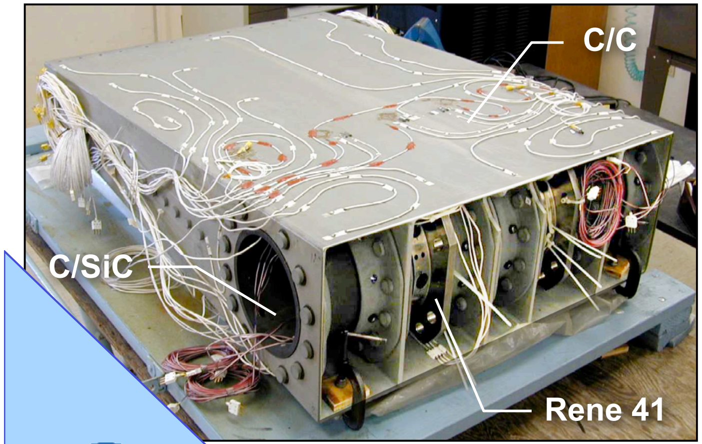


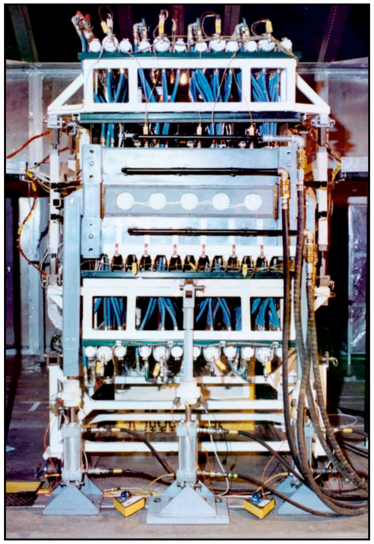


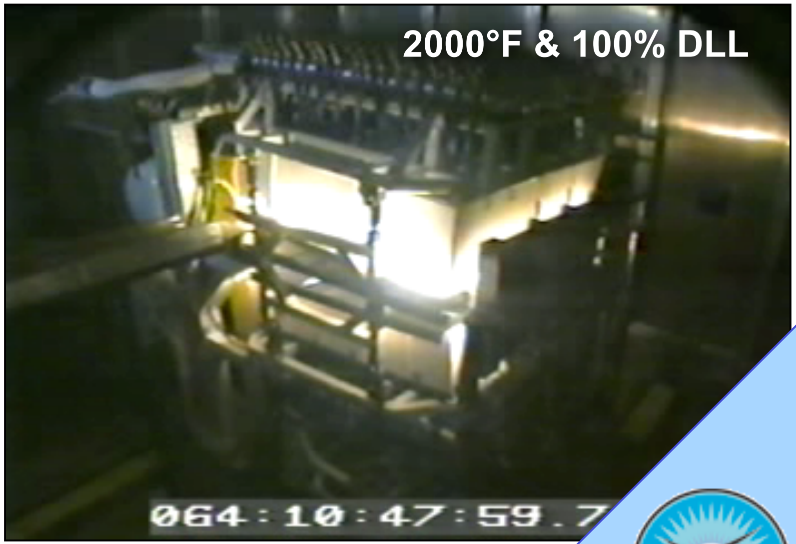
Thermal-Structural Test Programs

- NASP / NGLT Carbon-Carbon Elevon (2003)
  - Concept validation test of a flight-weight C/C hot structure component
  - Advanced C/C, C/SiC Torque Tube, Rene 41 fittings
  - Fabricated in 1989 for the NASP program
  - Simultaneous heating and loading to 2000°F and 100% DLL in nitrogen purged atmosphere
  - 128 quartz-lamp heaters (32 control zones)
  - Instrumentation
    - 50 thermocouples
    - 54 strain gages (14 fiber-optic strain sensors)



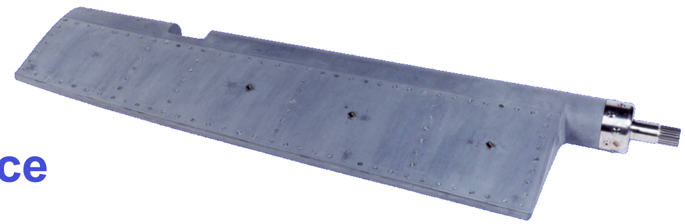


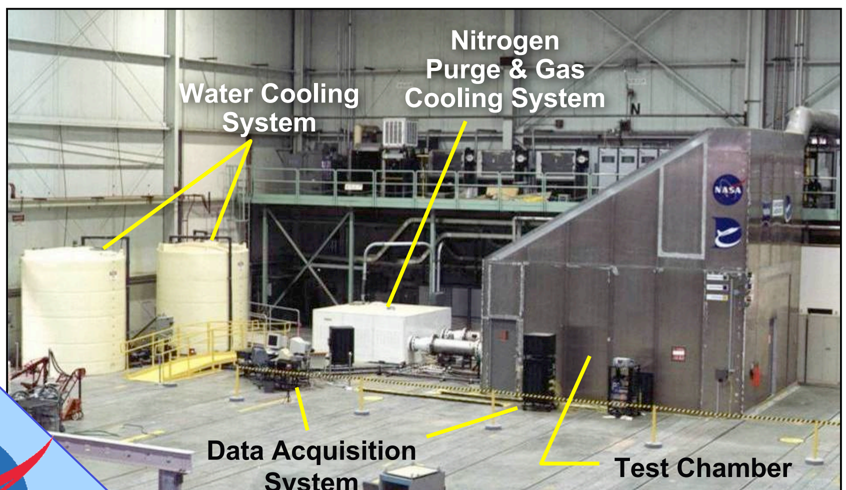


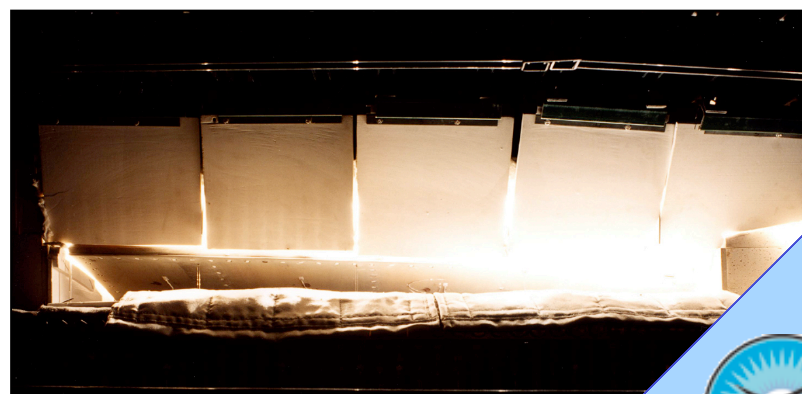


Thermal-Structural Test Programs

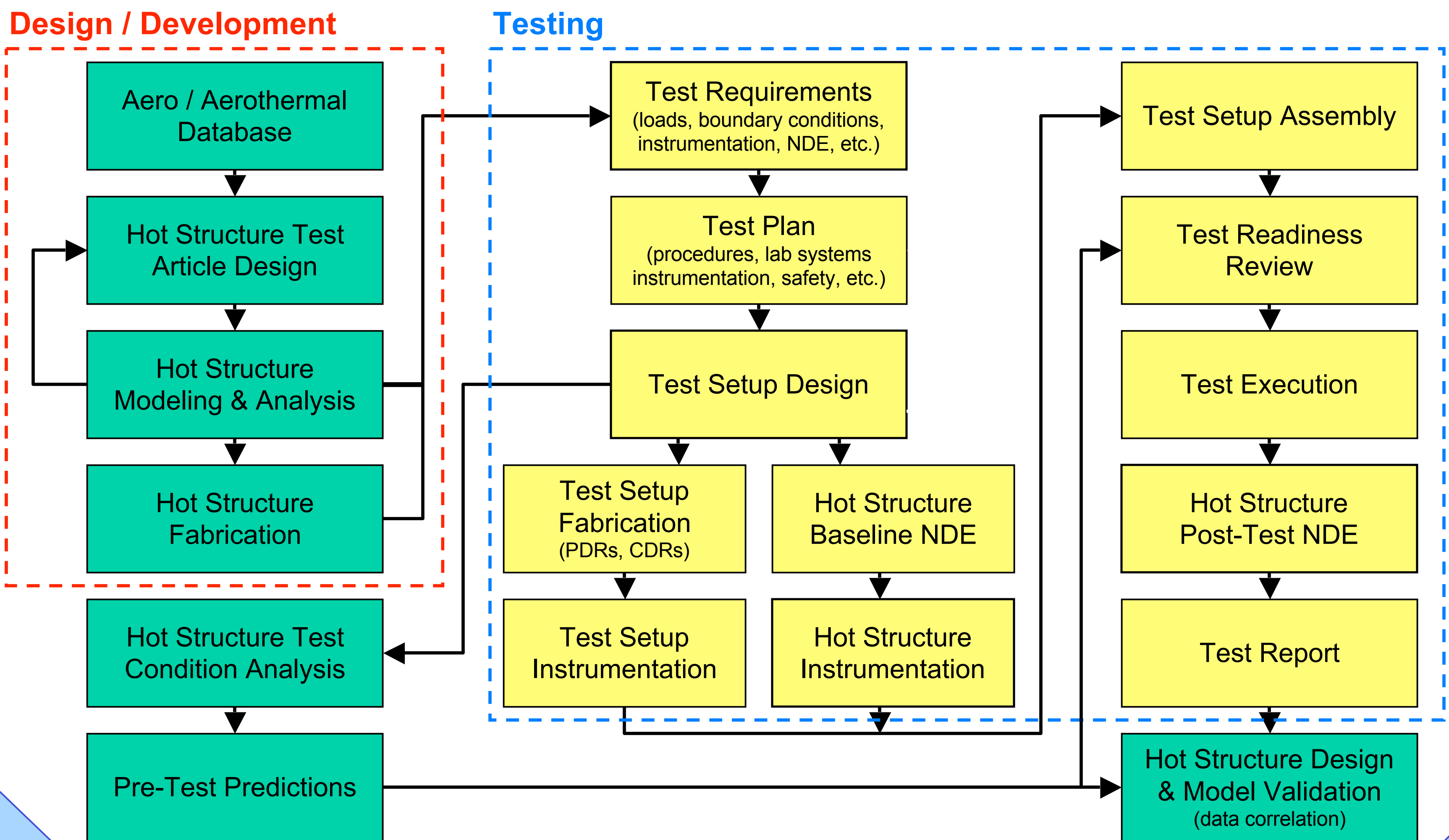
- X-37 Carbon-Carbon Flaperon (2005)
  - Thermal & mechanical qualification test of a flight-weight C/C hot structure control surface
  - Tested in nitrogen purged atmosphere
  - 35 quartz lamp heaters (18 control zones)
  - Instrumentation
    - 82 thermocouples
    - 14 fiber-optic strain sensors
    - 12 deflection measurements





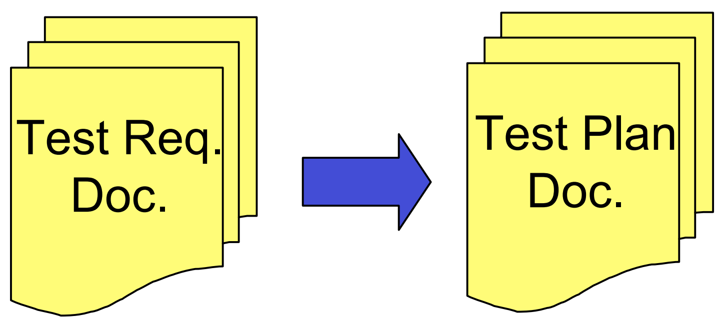


Thermal-Structural Test Flow Diagram



Thermal-Structural Test Development

- **Test Requirement Definition**
  - Test article description (material, size, type, etc.)
  - Type of test (proof, acceptance, qualification, validation, research)
  - Type of loading (thermal, mechanical, dynamic, combined)
  - Type of heating system (quartz lamp, graphite)
  - Type of test atmosphere (purged, air)
  - Instrumentation (type, number, location)
  - Boundary conditions (thermal, mechanical)
  - Test matrix definition (impact of test sequence on material/structure)
  - Handling requirements
  - Safety requirements
  - Inspection requirements
  - Reporting requirements

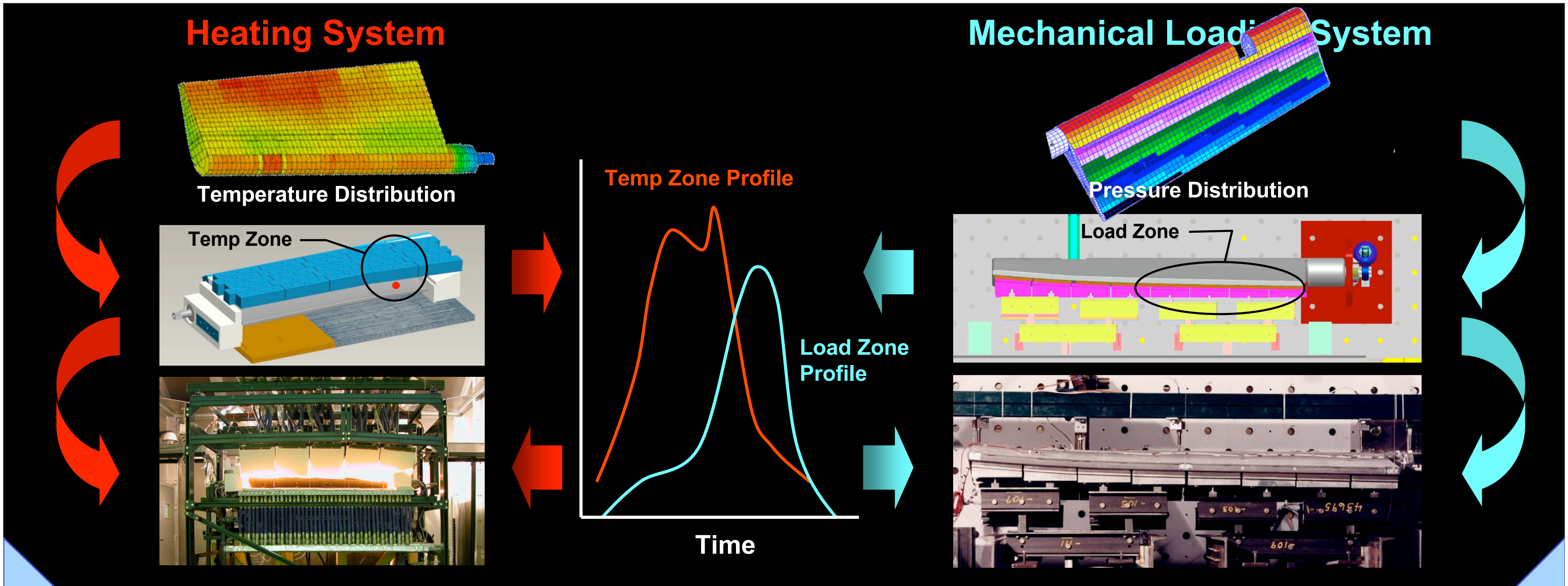


Negotiate customer requirements to fit within lab capabilities

Plan to meet negotiated customer requirements

Thermal-Structural Test Development

- **Goal: Design test setup to simulate <u>desired</u> load and boundary conditions**
  - **Heating system to meet desired temperature distribution**
  - **Mechanical loading system to meet desire pressure distribution**

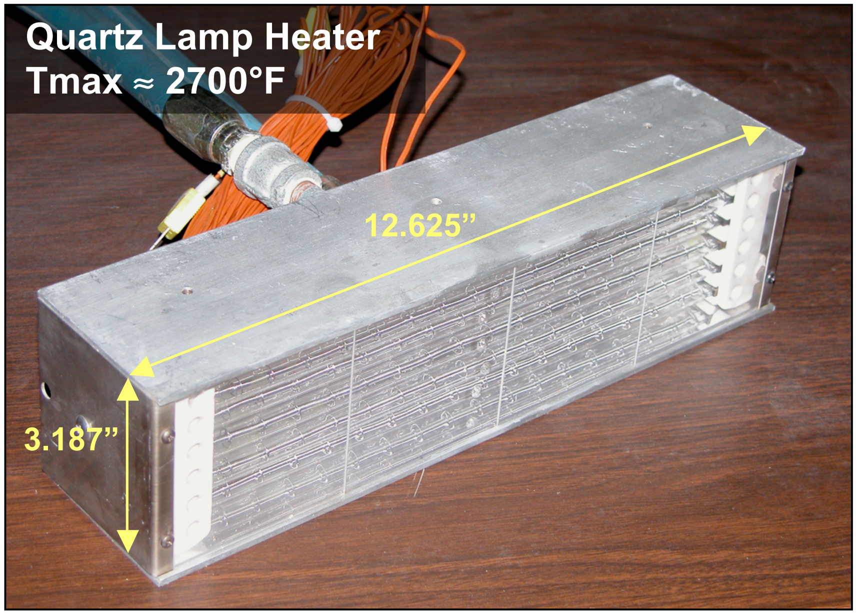


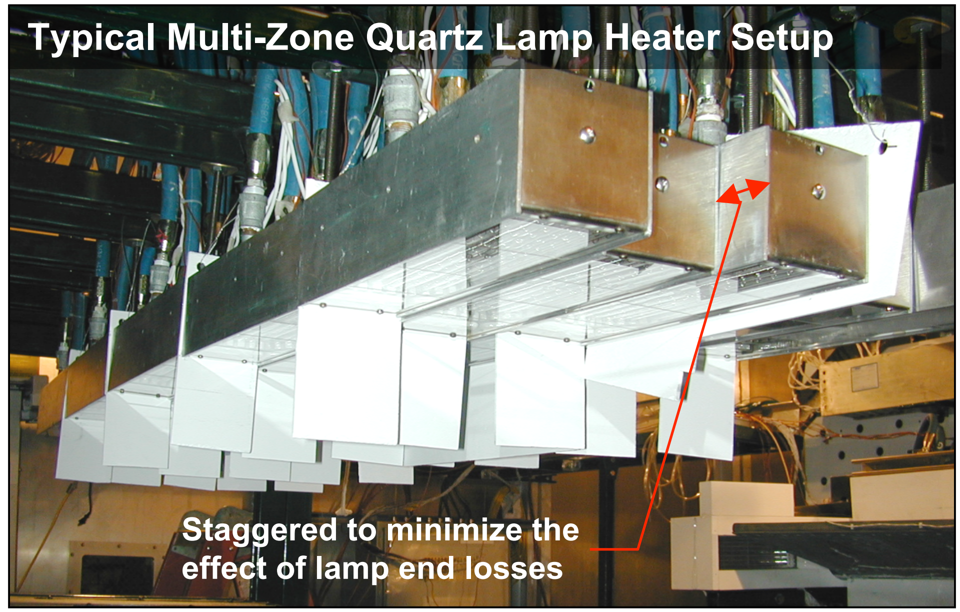
Thermal-Structural Test Development

- **Heating System Design Process**
  - Use the predicted aerodynamic heating to calculate the transient temperature response of the test article
  - Select locations on test article to temperature control
    - Use heat flux distribution and calculated test article temperatures to determine the required number of temperature control zones
    - Typically keep thermocouple locations away from heat sink areas on the test article
  - Select the appropriate type of heating system
    - Quartz lamp and/or graphite heaters depending upon temperature and heat flux requirements
  - Determine the heater layout
    - Arrange heaters into zones
      - Group heaters as required to approximate the predicted aerodynamic heating distribution
      - Extend heaters past the edges of the test article to minimize end effects
      - Stagger heaters to minimize effect of lamp end losses
    - Create heater boundary conditions
      - Separate zones with radiation barriers to minimize “cross-talk”
      - Use barriers around heaters to minimize edge effects and reduce natural / forced convection

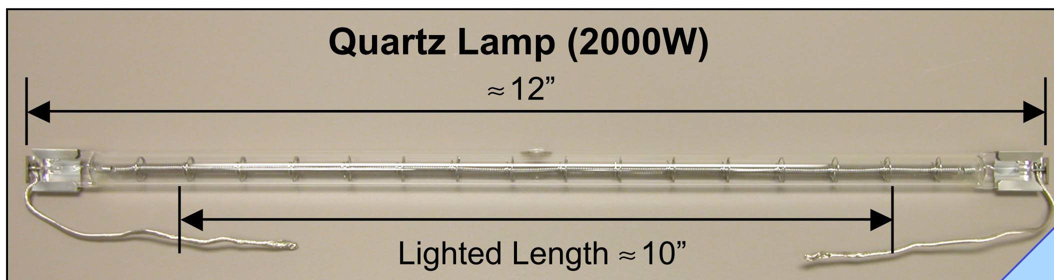
Thermal-Structural Test Development

Heating System Design Process – Heater Selection (Quartz Lamp)



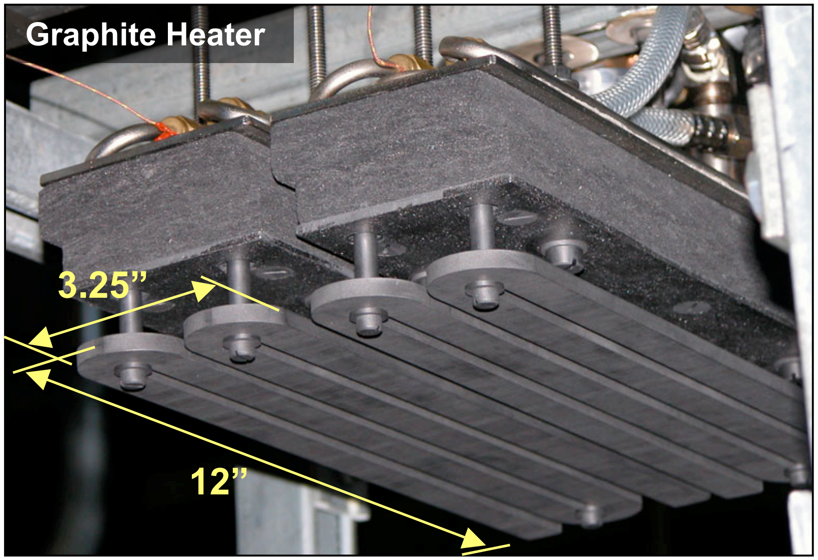


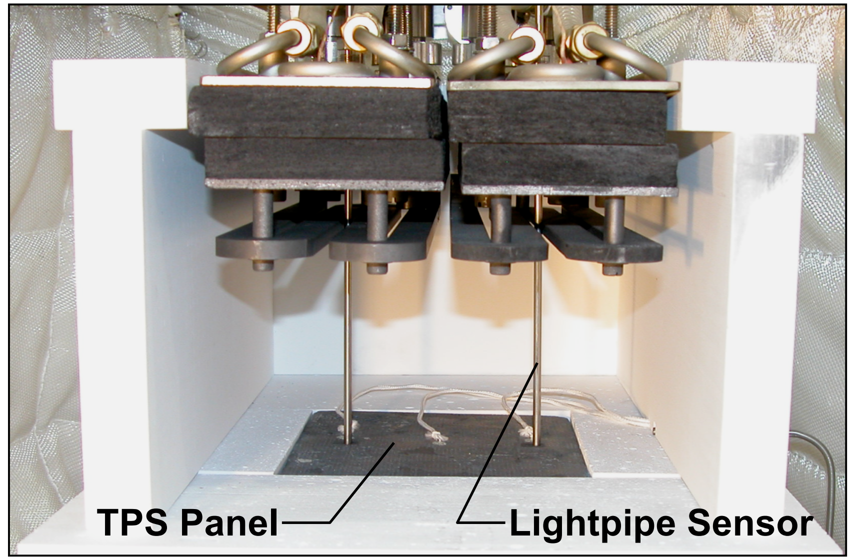
- For application <2700°F
- Polished aluminum reflector
- Water & gas cooled
- Quartz window
- Six 2000W quartz lamps
- 36KW @ 480V (double rated)



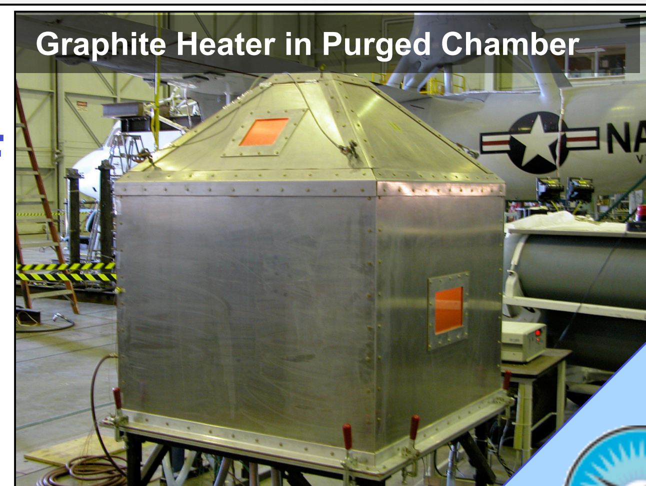
Thermal-Structural Test Development

Heating System Design Process – Heater Selection (Graphite Heater)





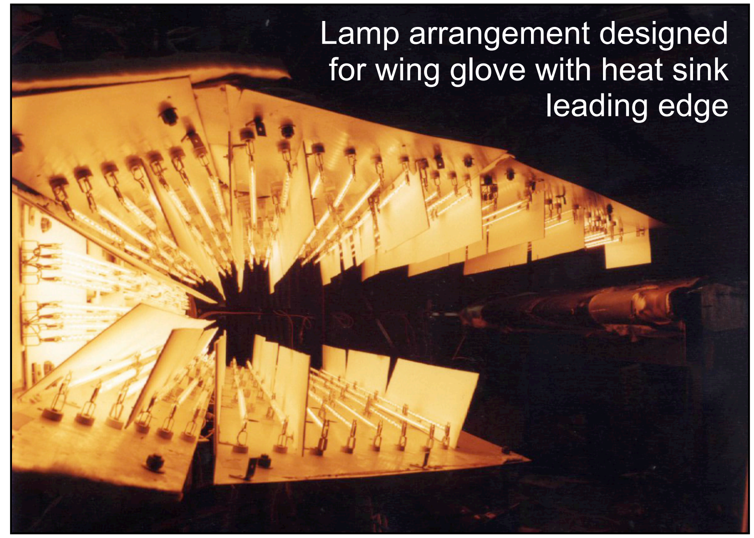
- For applications >2700°F
- Test article temperatures beyond 3000°F
- Requires purged environment

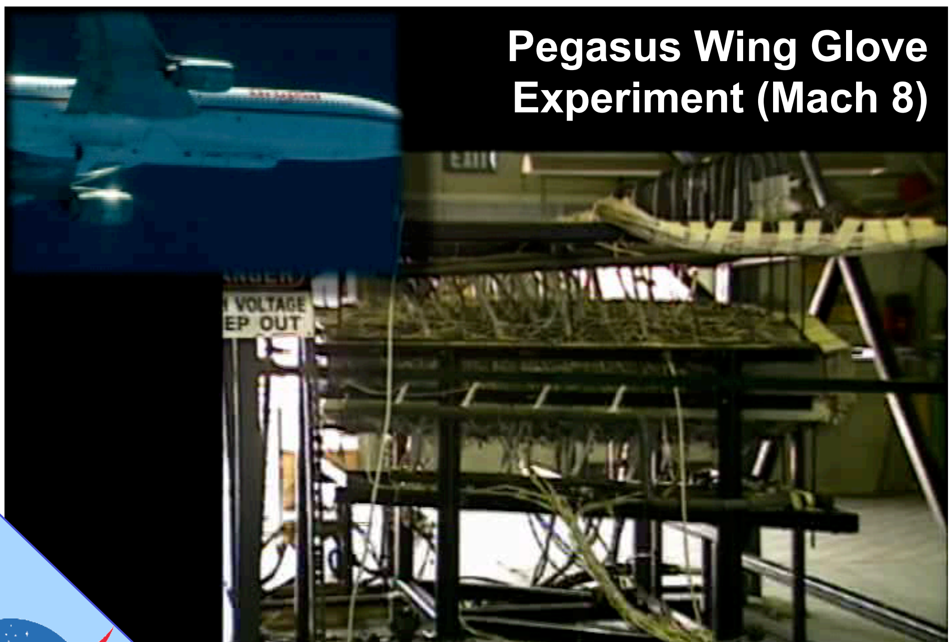


Thermal-Structural Test Development

Heating System Design Process – Heater Selection (Custom Heater)

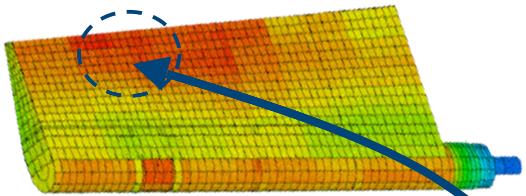
- **Custom heater designs are often required for unique heating applications**
- **Structures with heat sinks or complex shapes may require tailored lamp spacing, lamp lengths, and/or voltage requirements**


Lamp arrangement designed for wing glove with heat sink leading edge

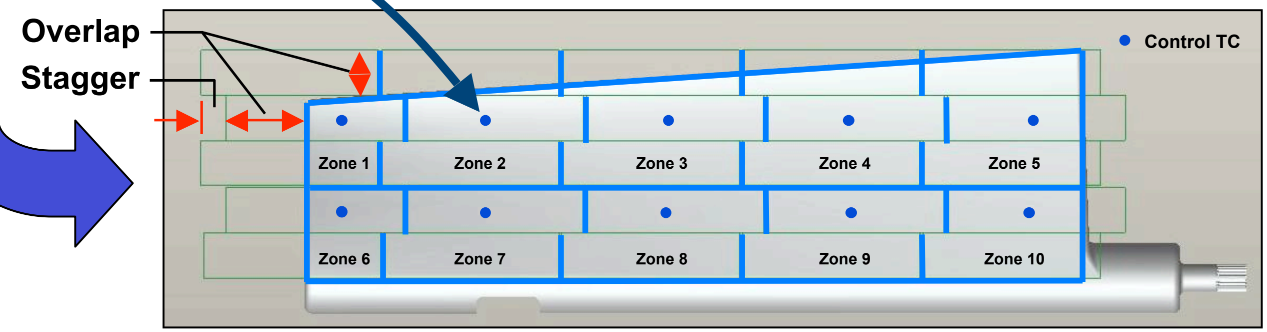

Pegasus Wing Glove Experiment (Mach 8)

Thermal-Structural Test Development

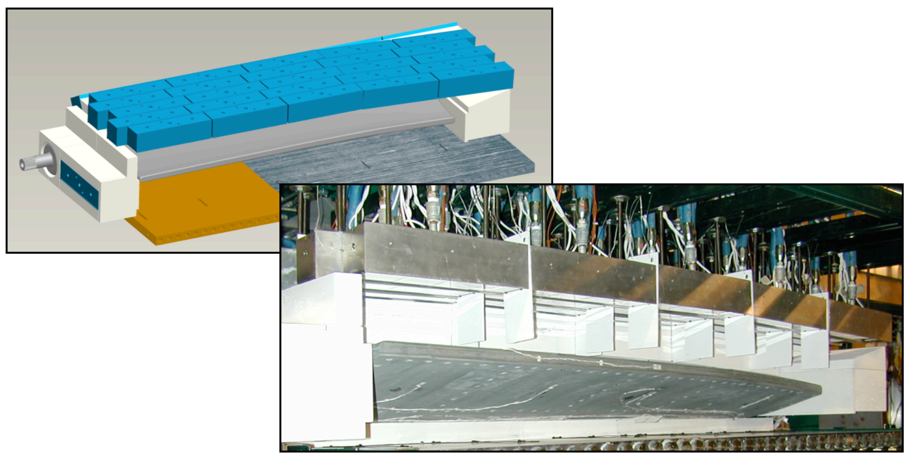
Heating System Design Process



Temperature Distribution on Finite Element Model



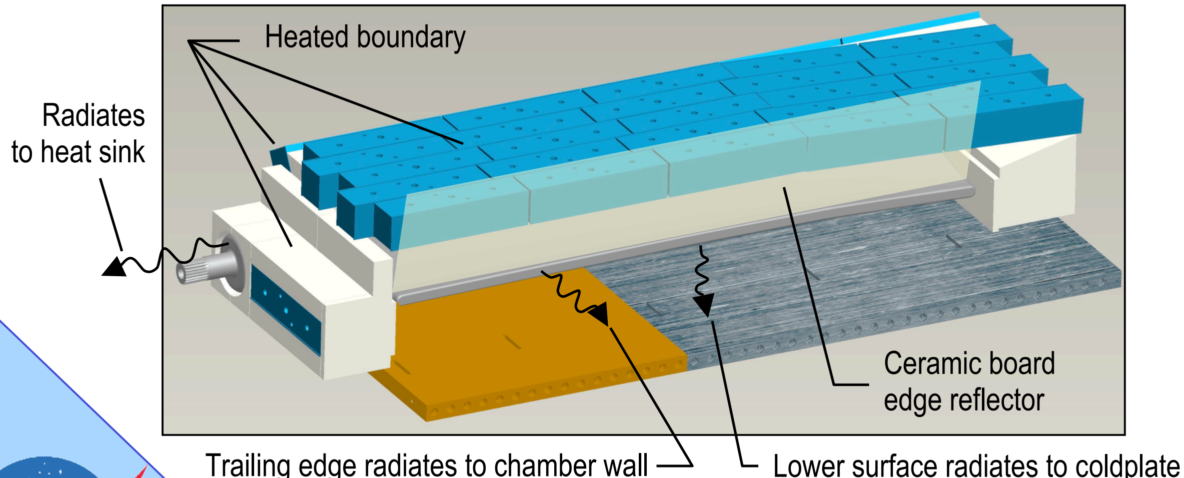
Heater Selection & Heating Zone Layout

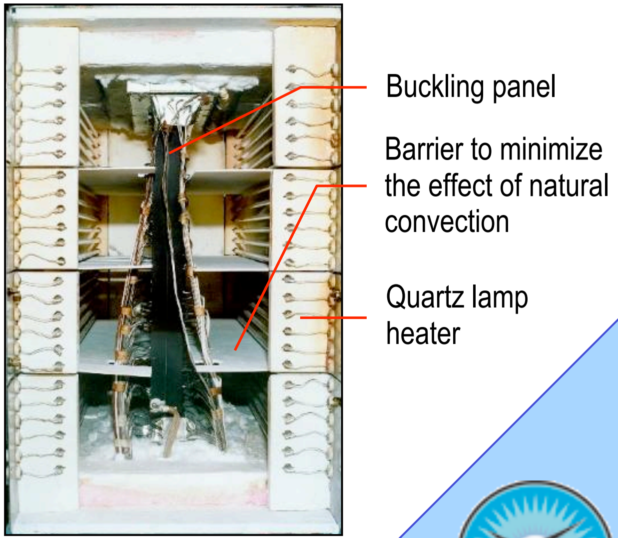


Heating System Design & Fab

Thermal-Structural Test Development

- **Heating System Design Process – Thermal Boundary Conditions**
  - Test article radiates to
    - Space (test area)
    - Controlled temperature boundary (heat exchanger,coldplate, heaters)
    - Temperature varying boundary (heat sinks, insulated surfaces)
  - Use end / edge reflectors around heaters to minimize end effects
    - End reflectors simulate having heaters that extend past test article edge
    - Can use reflective plates, ceramic boards, etc.
  - Use barriers around heating system to minimize the effect of natural and forced convection

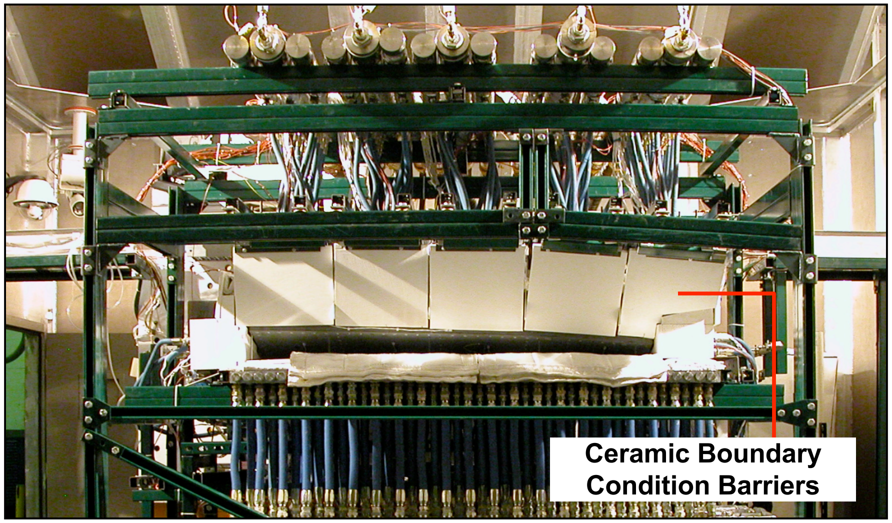


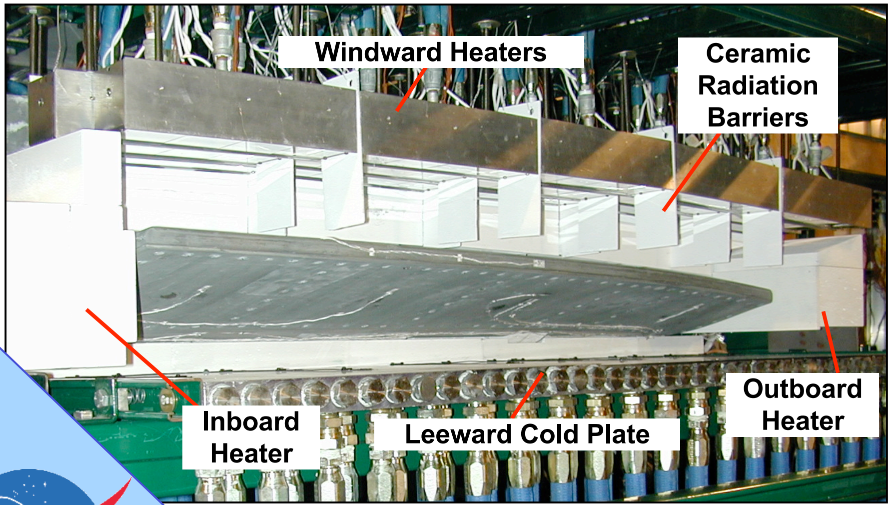


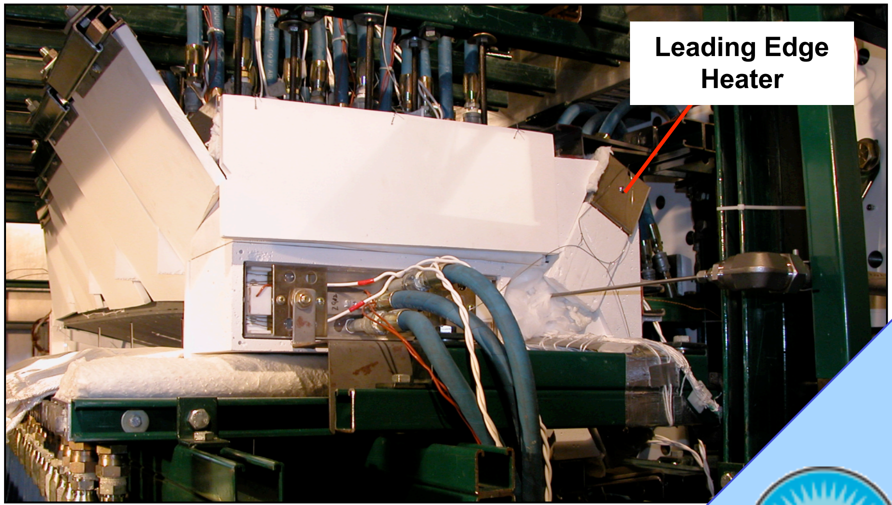
Thermal-Structural Test Development

Heating System Design Process

- **Test Conditions**
  - Thermal simulation in a nitrogen purged atmosphere
- **Thermal Boundary Conditions**
  - Heating on windward, leading edge, inboard/outboard surfaces
  - Leeward surface radiated to constant temperature coldplate
  - Trailing edge radiates to chamber

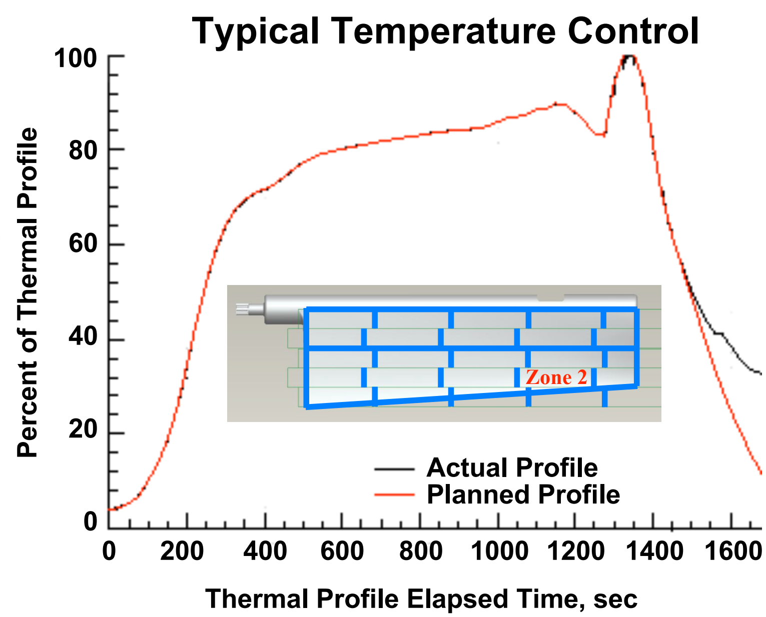


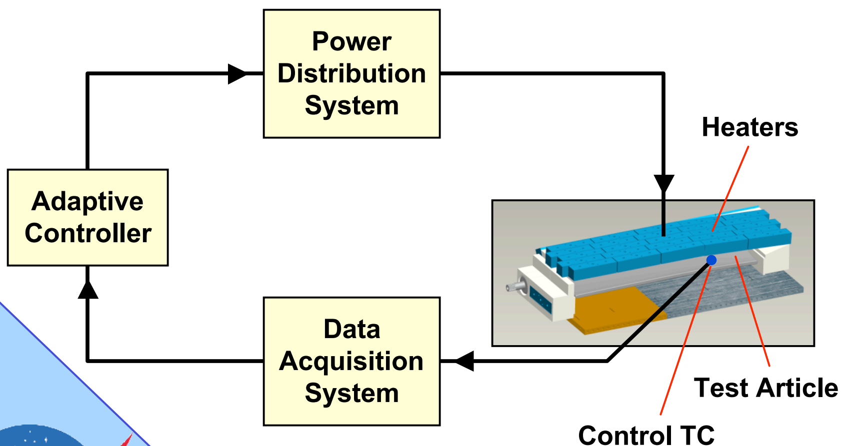


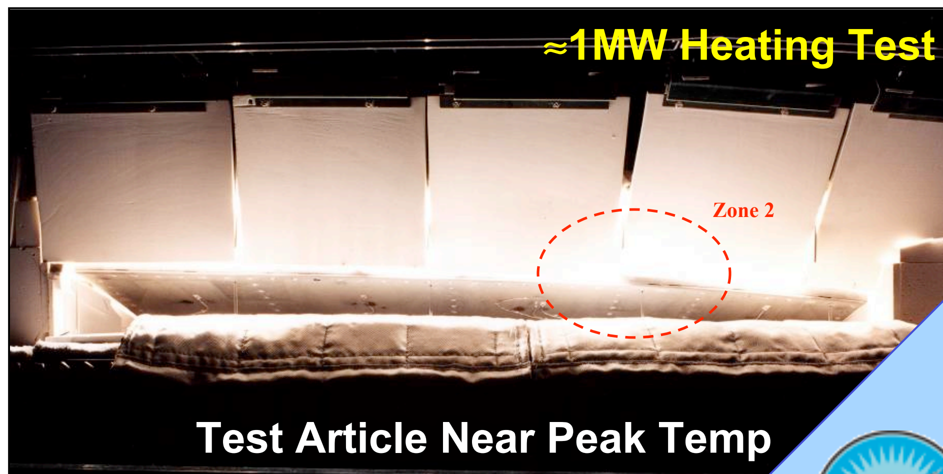


Thermal-Structural Test Development

Heating System Design Process





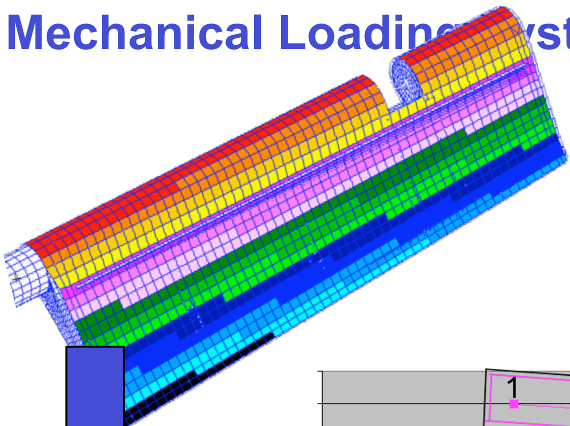


Thermal-Structural Test Development

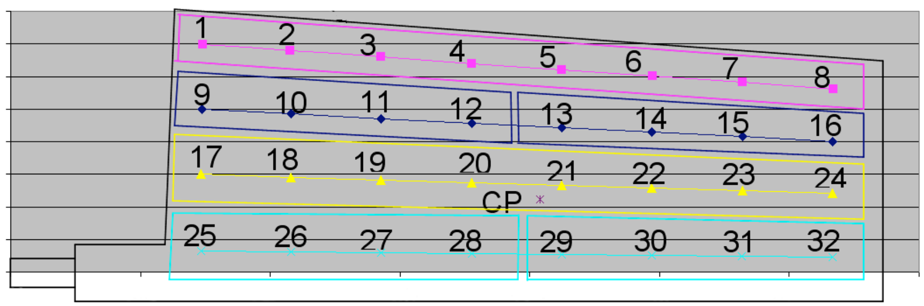
- **Mechanical Loading System Design Process**
  - Use the predicted aerodynamic loads to calculate the pressure load distribution on the test article
  - If mechanical loading is combined with heating
    - Introduce loads into test article at hard points or at locations where the loading system will not adversely affect test article heating
  - If mechanical loading is not combined with heating
    - For re-entry heating simulation, aerodynamic and aerothermal loading is usually separated in time so they can be treated as separate events
    - Design loading system to closely match distributed pressure loading
    - Conformal load pads are used to apply distributed pressure loading
    - Use whiffle-tree loading system to distribute loads to the load pads

Thermal-Structural Test Development

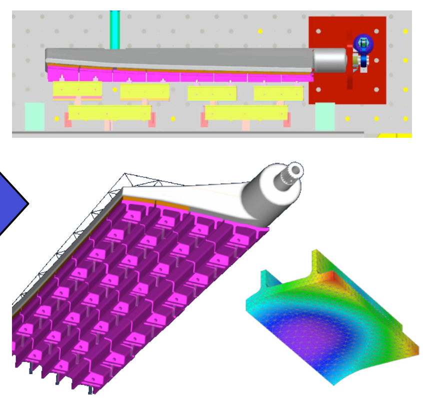
Mechanical Loading System Design Process

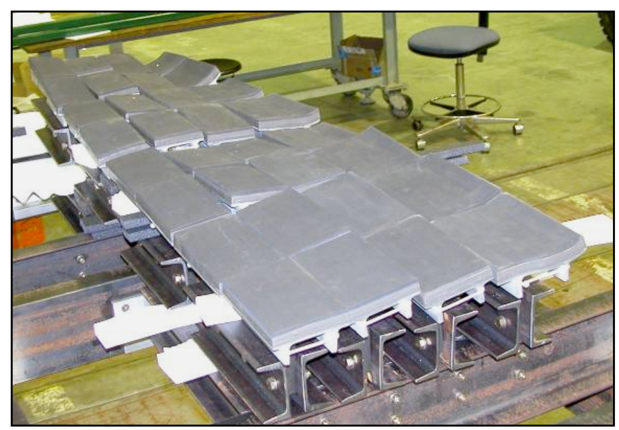


Pressure Distribution on Finite Element Model



Load Pad Layout

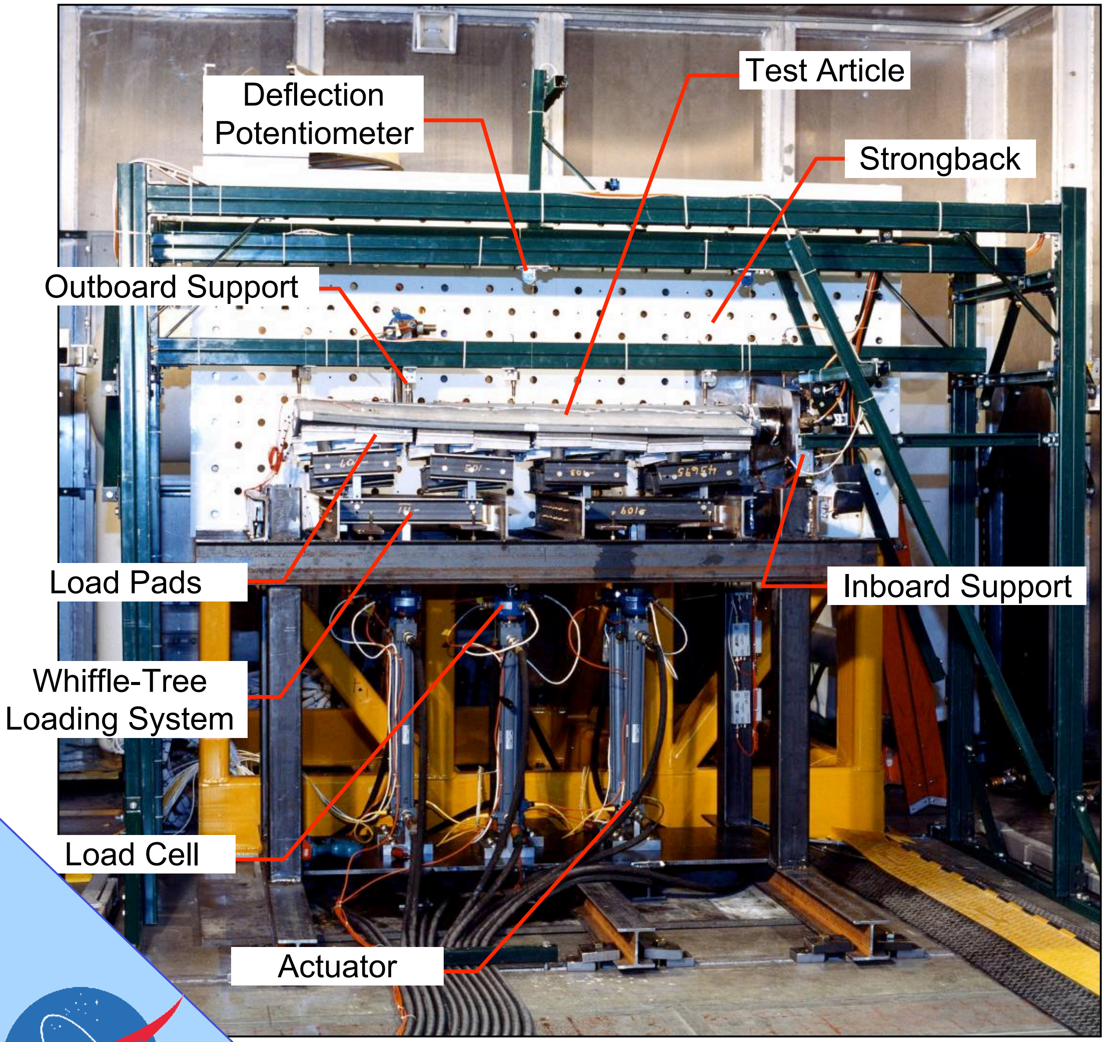


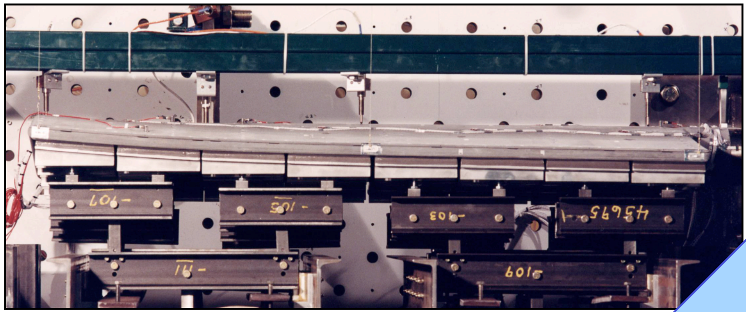


Load Pad Design & Fab

Thermal-Structural Test Development

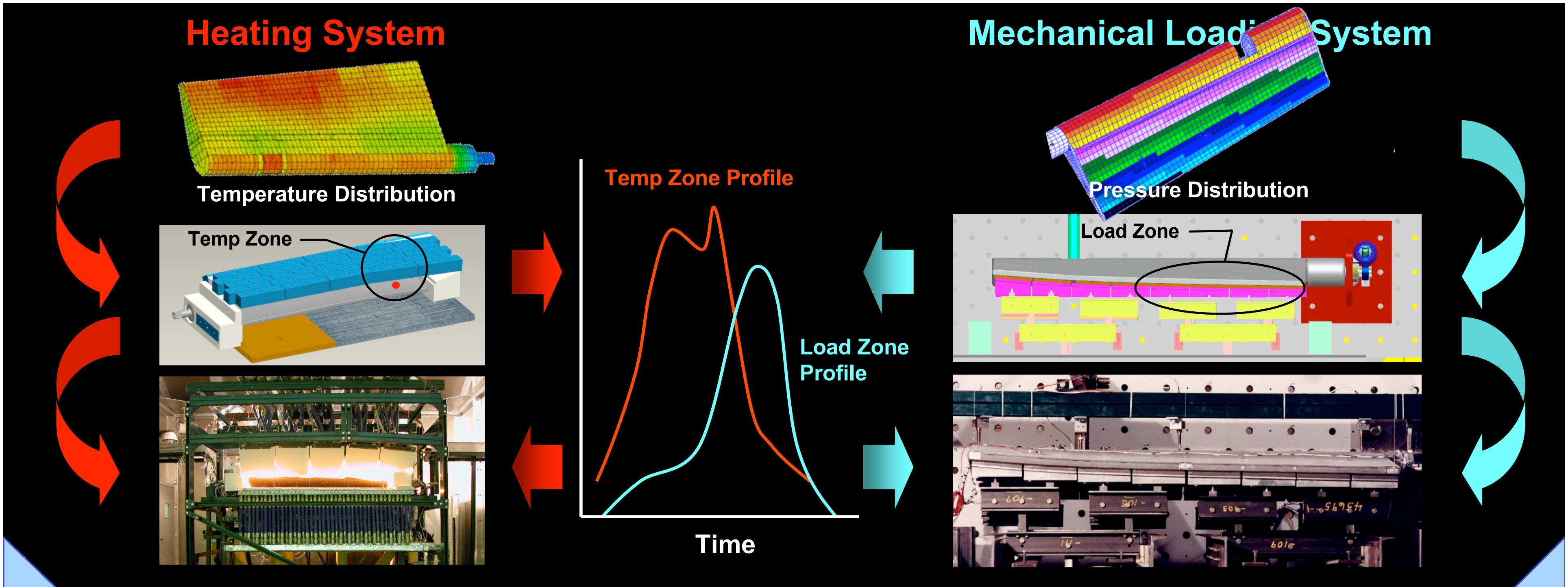
Mechanical Loading System Design Process





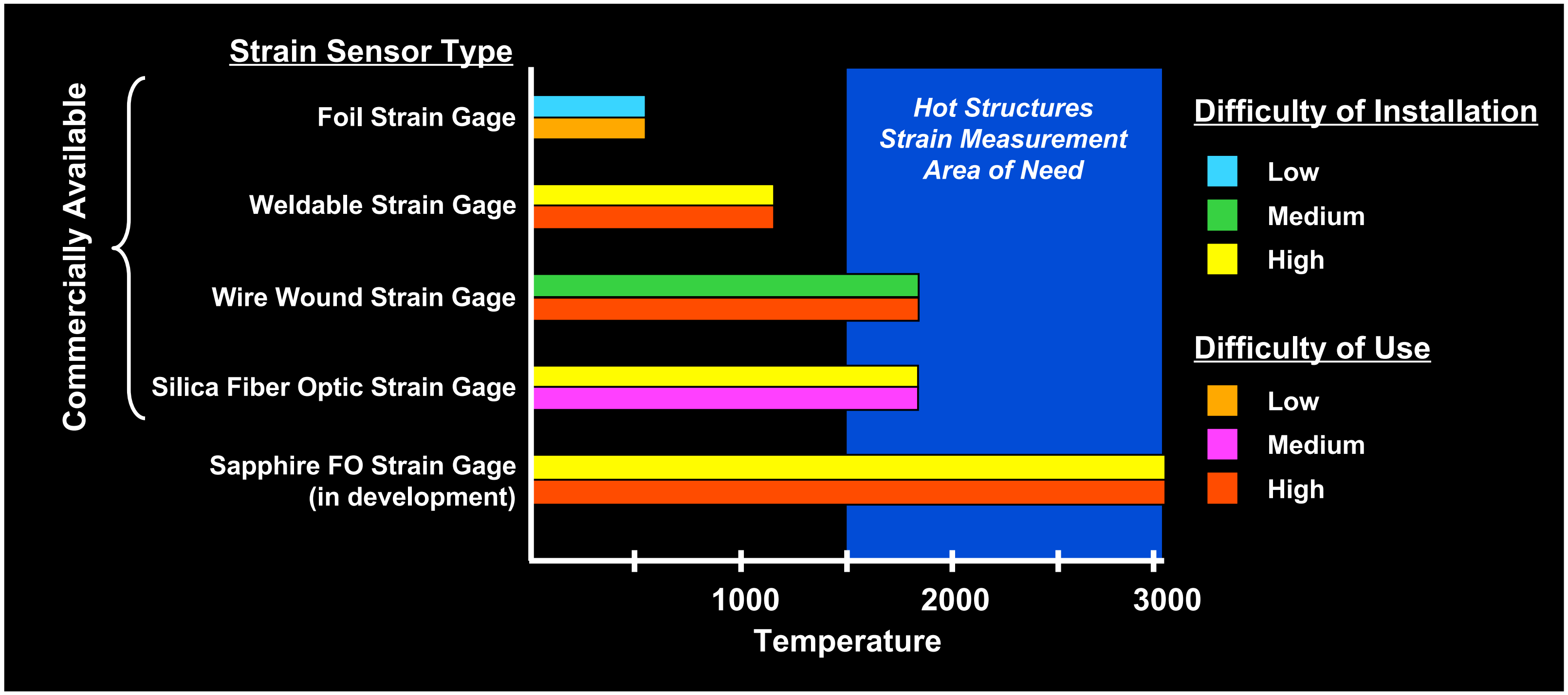
Thermal-Structural Test Development

- Goal: Design test setup to simulate desired load and boundary conditions
  - Heating system to meet desired temperature distribution
  - Mechanical loading system to meet desire pressure distribution



- Perform a test condition analysis using actual boundary conditions
  - Provides more representative pre-test predictions
  - Provides best correlation between test data and analysis

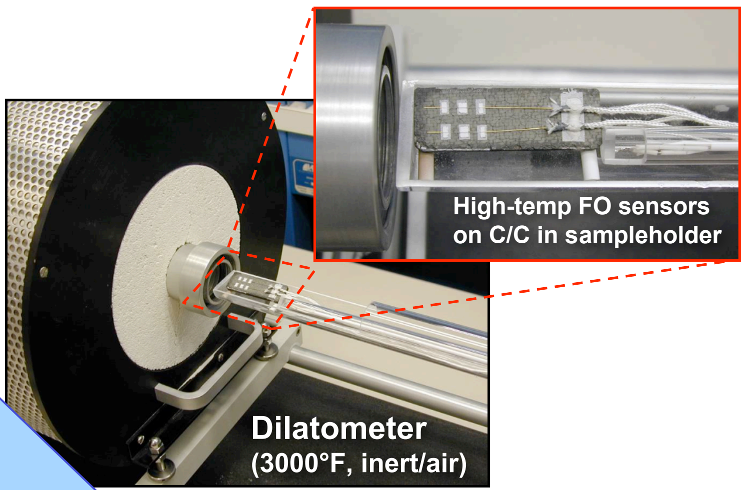
Thermal-Structural Test Instrumentation

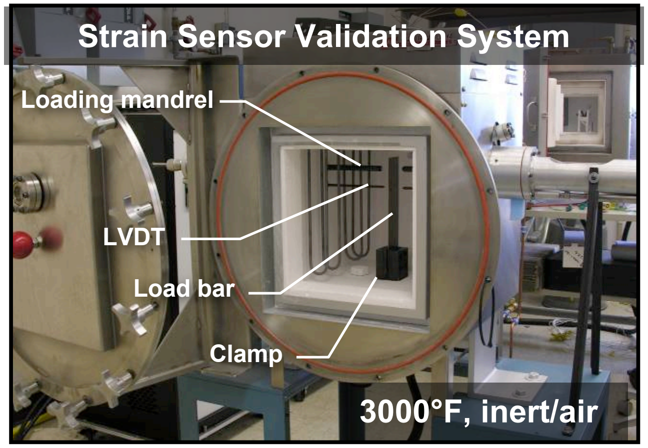


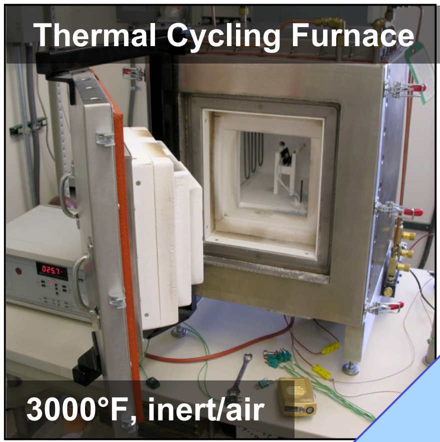
- Issues
  - Hypersonic structures are utilizing advanced materials that operate at temperatures that exceed current abilities to measure structural performance
  - Robust strain sensors that operate accurately and reliably beyond 1800°F do not exist
- Implications
  - Hinders ability to validate analysis and modeling techniques
  - Hinders ability to optimize structural designs

Thermal-Structural Test Instrumentation

- **Goal: Provide valid strain and temperature data to analysts**
  - Supports the validation of finite element modeling techniques and thermal-structural analysis
- **Key Issue: Develop attachment techniques for strain & temperature sensors on hot structure materials (C/SiC & C/C)**
  - Validate attachment techniques through characterization testing

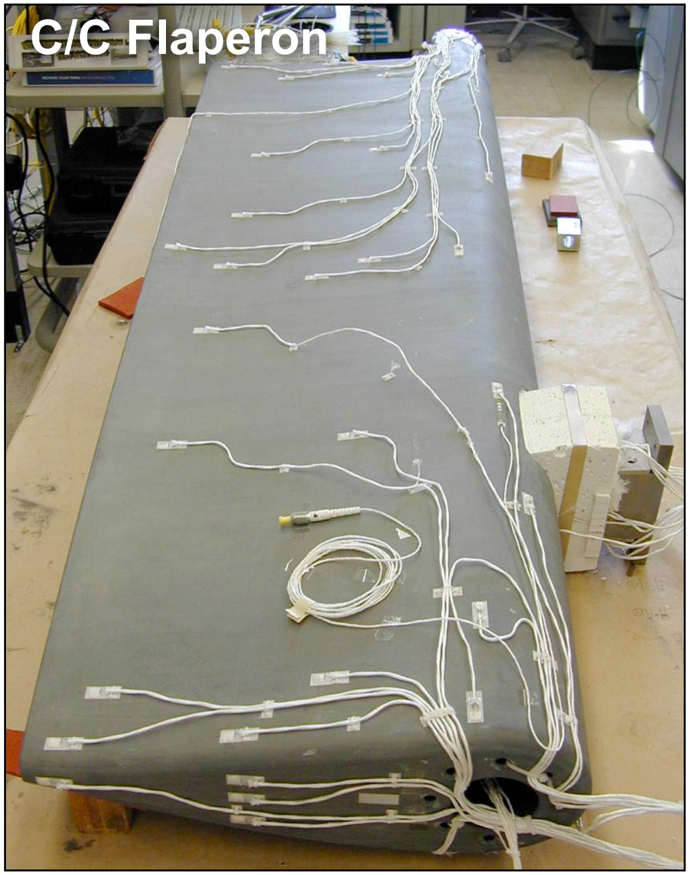


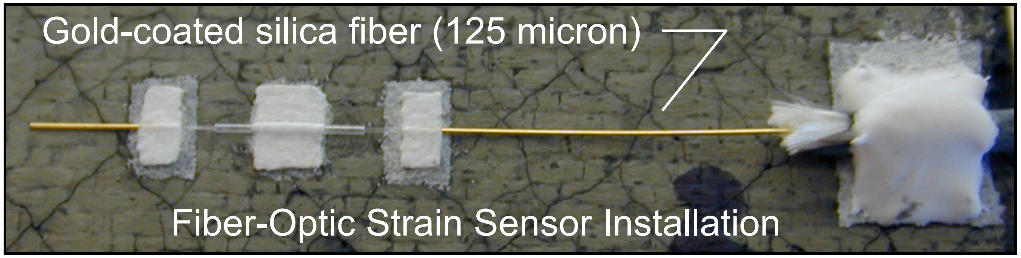


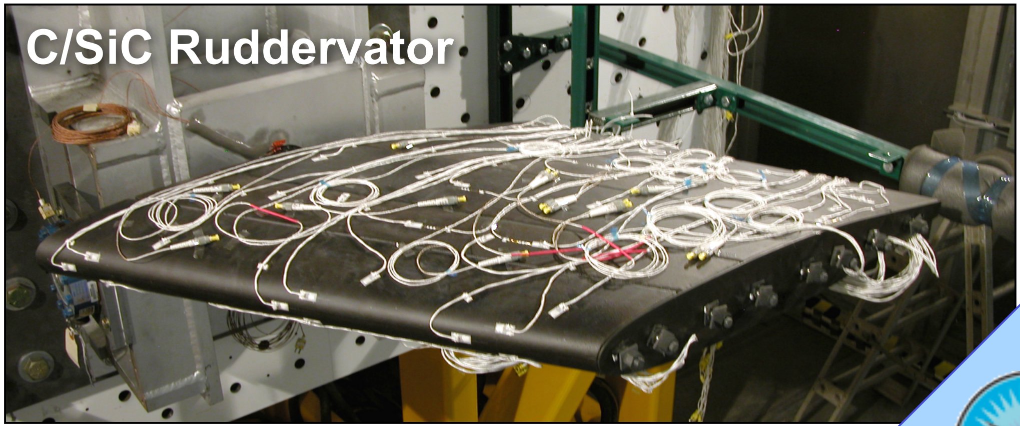


Typical Systems for Sensor Validation Testing

Thermal-Structural Test Instrumentation





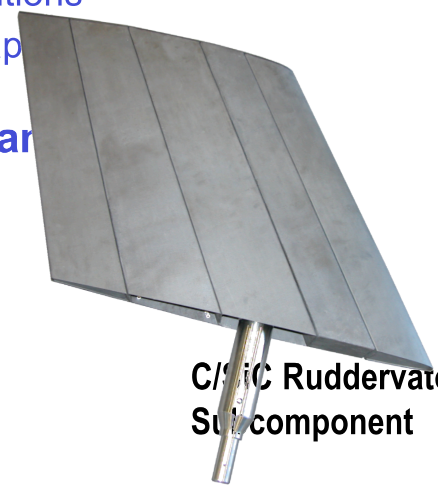


Thermal-Structural Testing Challenges

- **Instrumentation**
  - Developing higher temperature strain, temperature, heat flux, and accelerometer sensors
  - Sensor attachment techniques on hypersonic materials (C/SiC, C/C, SiC/SiC, etc.)
  - Sensor validation testing
- **Test Technique Development**
  - Controlling heating via heat flux
  - High-temperature modal survey of hypersonic components / vehicles
  - Non-contact methods of sensing strain and temperature beyond 2500°F
- **Non-Destructive Evaluation**
  - Developing techniques to inspect hypersonic structures to support ground and flight applications
  - Engineered calibration standards for hypersonic materials
- **Maintaining U.S. core competencies in large-scale thermal-structural test capabilities (test systems & skilled workforce)**

Current Thermal-Structural Test Activity

- **Objective: Test a C/SiC Ruddervator Subcomponent under relevant thermal, mechanical & dynamic loading**
  - Thermal-structural mission cycling for re-entry and hypersonic cruise conditions
  - High-temperature modal survey to study the effect of heating on mode shap natural frequencies and damping
- **Supports NASA ARMD Hypersonics Material & Structures Program**
- **Partners: NASA Dryden / Langley / Glenn, Lockheed-Martin, Materials Research & Design, GE CCP**
- **Test Phases**
  - Phase 1: Acoustic-Vibration Testing (LaRC) – completed
  - Phase 2: Thermal-Mechanical Testing (DFRC) – in assembly
  - Phase 3: Mechanical Testing (DFRC) – in assembly



C/SiC Ruddervator Subcomponent